Wind Turbine Performance, Control and Design
AME 40530

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Lecture #2 Modern Wind Turbines

Lecture # 2 Outline

- Review of the current state of the art of Vertical and Horizontal Axis Wind Turbines. (VAWT and HAWT)
- The potential of Wind Power In the USA and abroad.
- Challenges facing the Wind Power Industry.
- Technologies that can be used to improve the next generation wind turbines.

Examples of Vertical Axis Wind Turbines (VAWT)

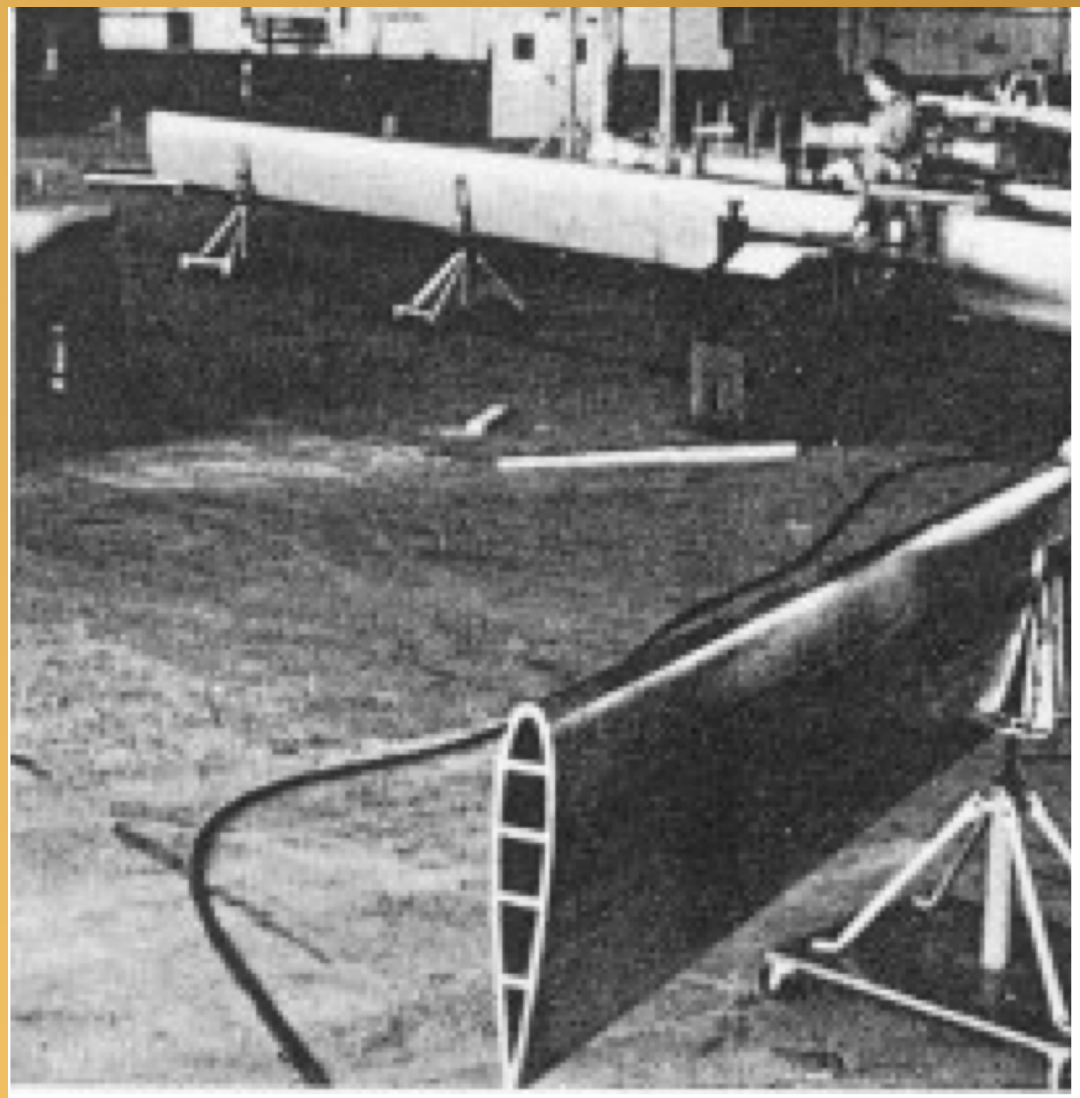
Vertical Axis Wind Turbines

- VAWT machines use either aerodynamic lift or drag to extract power from the wind.
  - In 1931, a French engineer Georges Jean Marie Darrieus patented the Darrieus wind turbine. The basic driving force is from the lift on the blades.
  - In 1922, a Finnish engineer Sigurd Johannes Savonius invented a simple turbine consisting of two or three scoops. This machine used the aerodynamic drag to extract power from the wind.

Darrieus VAWT Blades are made from airfoil sections.

The largest Darrieus wind turbine is located is the Eole turbine located in Cap-Chat, Quebec Canada. The turbine is 100 m tall and 60m wide.

It is used only occasionally because of fatigue issues.



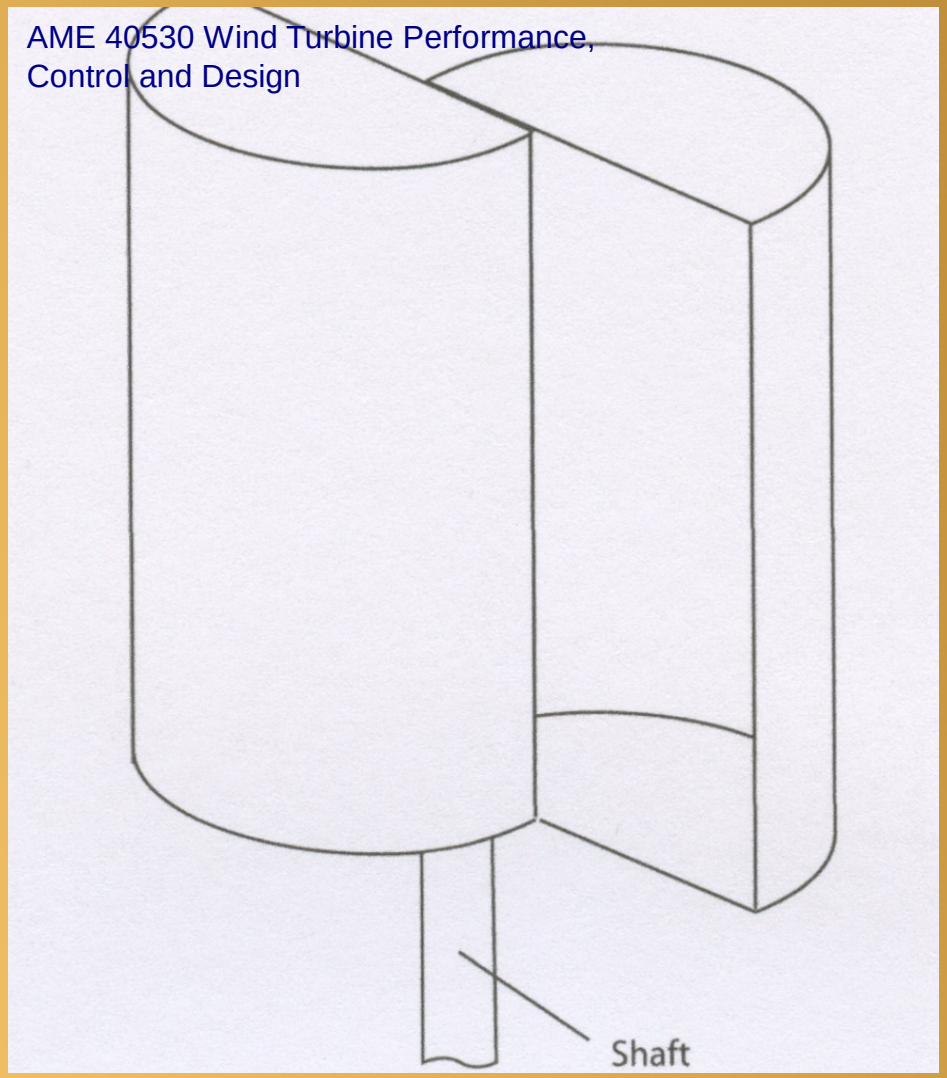
Darrieus Wind Turbine Fabrication

Darrieus Design Accidents

- An Alcoa 12.8 m diameter machine collapsed at their Pennsylvania facility on March 21, 1980 when the central torque tube began vibrating and ultimately buckled.
- In April 1981 a 25m diameter machine came apart east of Los Angeles do to a failure in the software that regulated the turbine rotational speed.
- Alcoa Corporation decided to close down the wind turbine operation.

VAWT Giromill

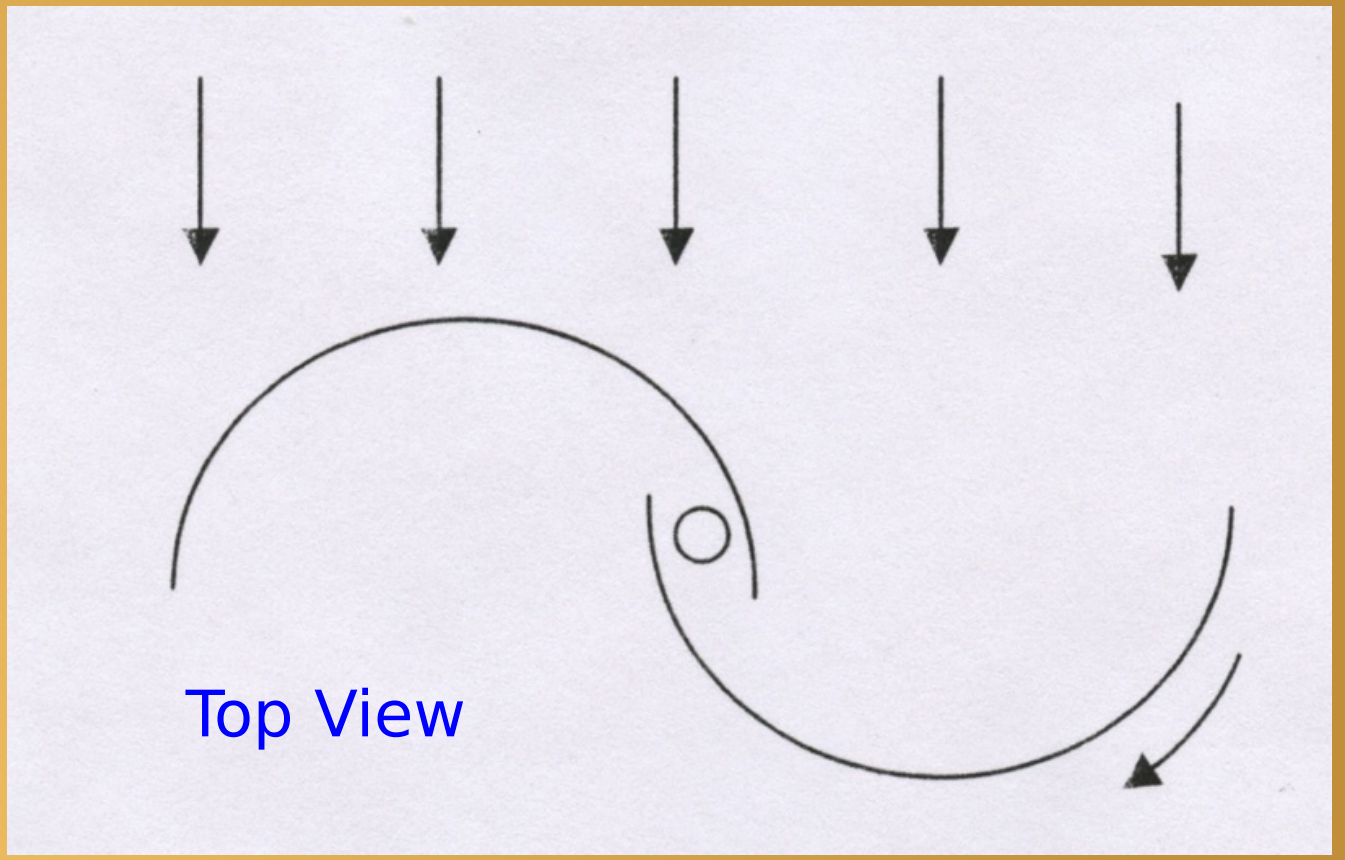
Has blades made from airfoil sections. The blade angles can be controlled. This machine uses lift to generate power.

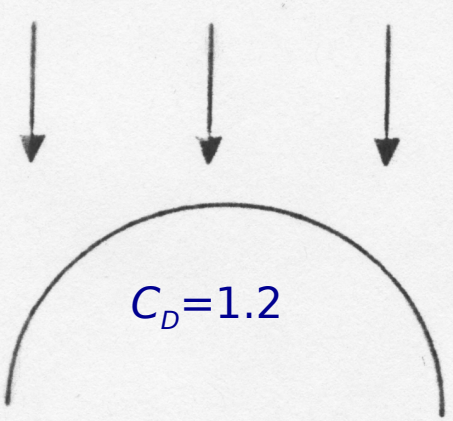


Savonius VAWT

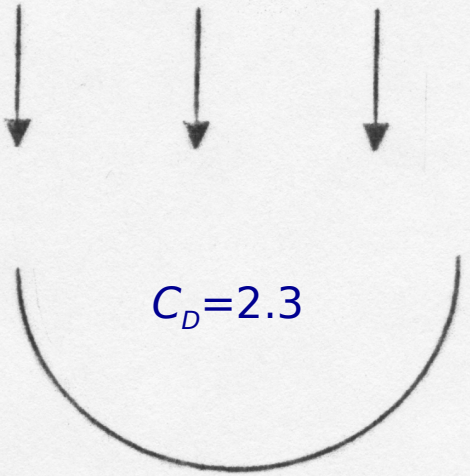
This machine uses drag to create power

Savonious VAWT





C_D=1.2

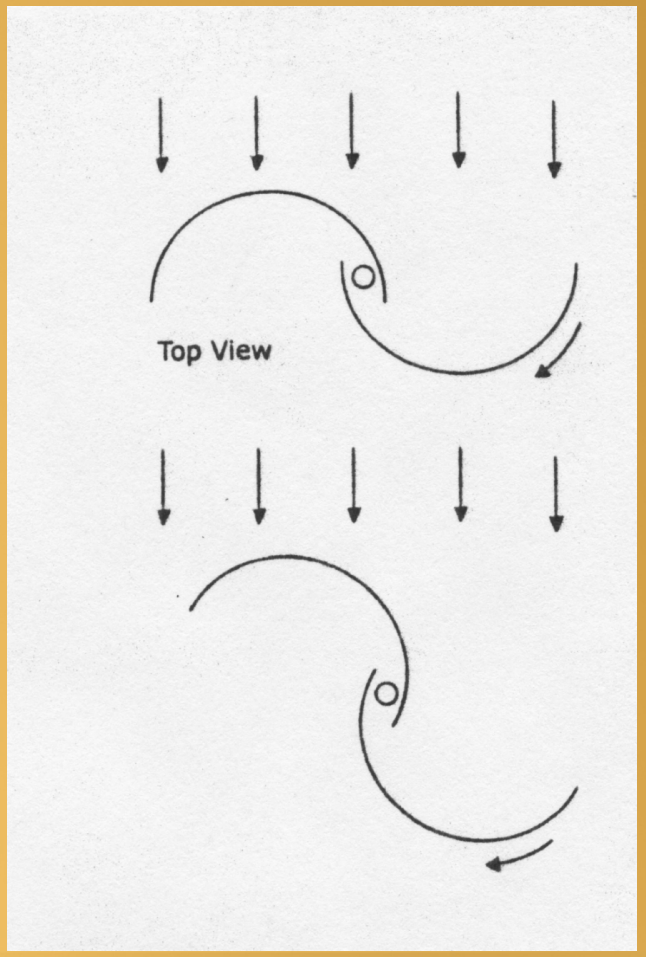


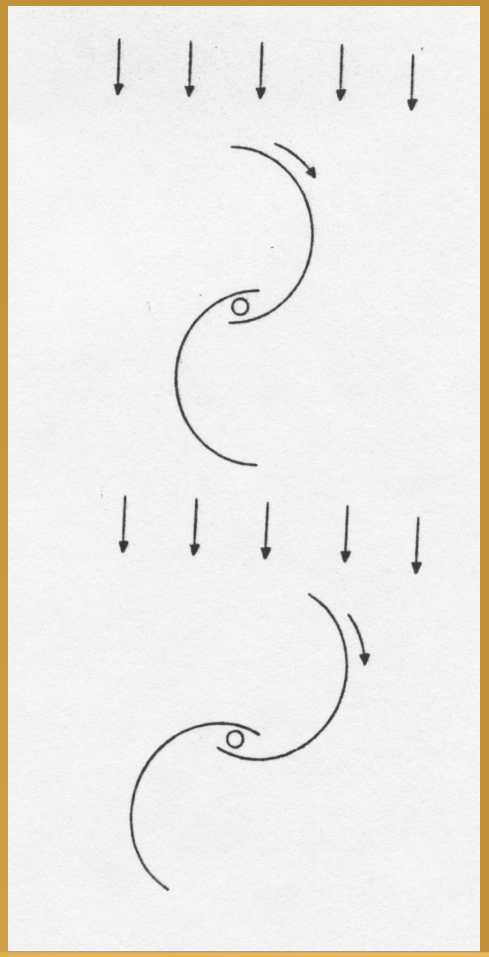
C_D=2.3

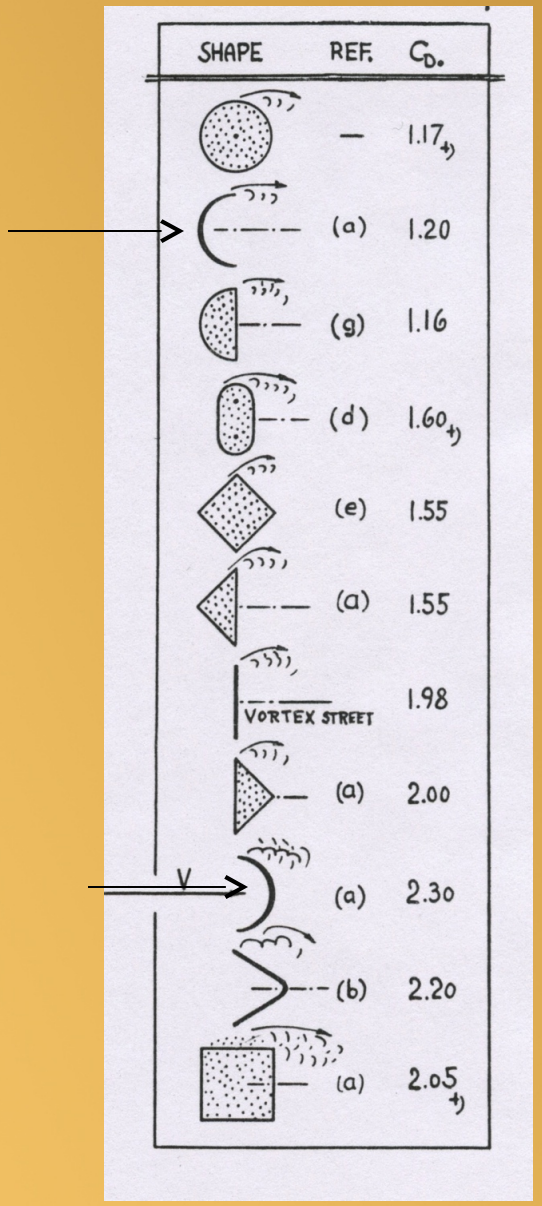
The drag force $D=C_D q_\infty S$

where C_D is the drag coefficient, q_∞ is the dynamic pressure, $q_\infty=1/2\rho V_\infty^2$ and S is the frontal area.

Differential Drag causes the Savonius rotor to rotate



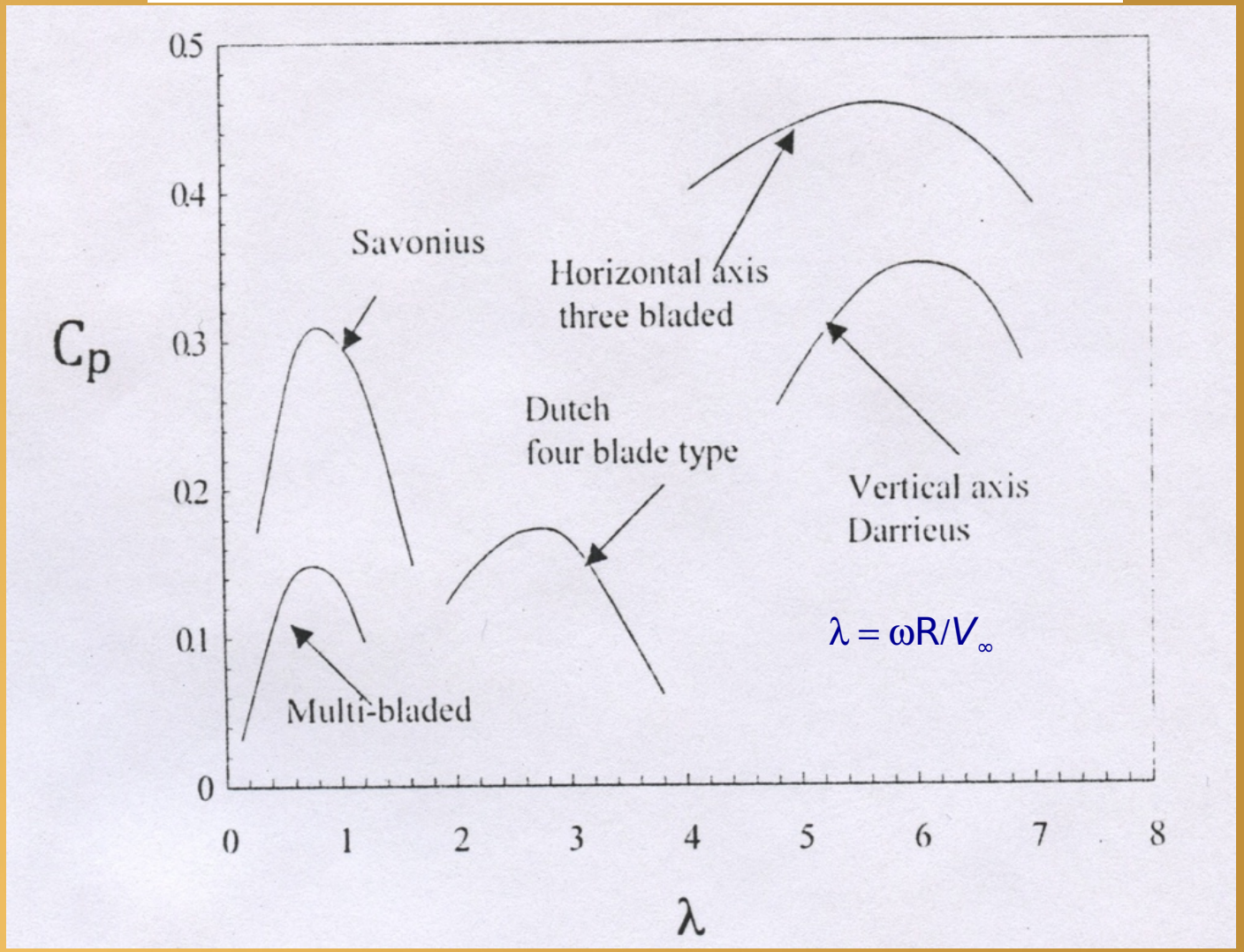




Drag coefficient data for various two dimensional shapes from Hoerner's book entitled Fluid-Dynamic Drag

A VAWT combining the Darrieus and Savanious designs

Power Coefficient Versus Tip Speed Ratio



Advantages of VAWT

- Gear box, generator and other components are located on the ground providing easy accessibility for maintenance.
- Turbine does not need to be pointed into the wind.
- They are practical for residential and urban areas.
- Can be used to power storage batteries to power remote site sensors.
- Relatively low production and installation cost.

Disadvantages of VAWT

- They are less efficient than HAWT.
- Air flow near the ground can be unsteady do to wakes from near by objects. This may cause unsteady loading and vibrations of the turbine. The vibration can result in noise and bearing wear.
- Guy wires for larger machines may be impractical on farms and recreational areas.

Darrieus Wind Turbine Design

- Of all the VAWT designs the Darrieus wind turbine is the best. So why is the Darrieus wind turbine design not used by the Wind Power Industry?
  - As shown earlier the Darrieus machines developed many unanticipated problems when they were first introduced in services. This coupled with the success of three bladed HAWT machines virtually eliminated this design for the wind power industry.
  - A later study by Sandia Lab study showed that the initial problems with the Darrieus design could be overcome.

Examples of Horizontal Axis Wind Turbines (HAWT)

Enercon E-126 Wind turbine

One of the world's largest wind turbines has a rotor blade diameter of 126m (413.3 ft)

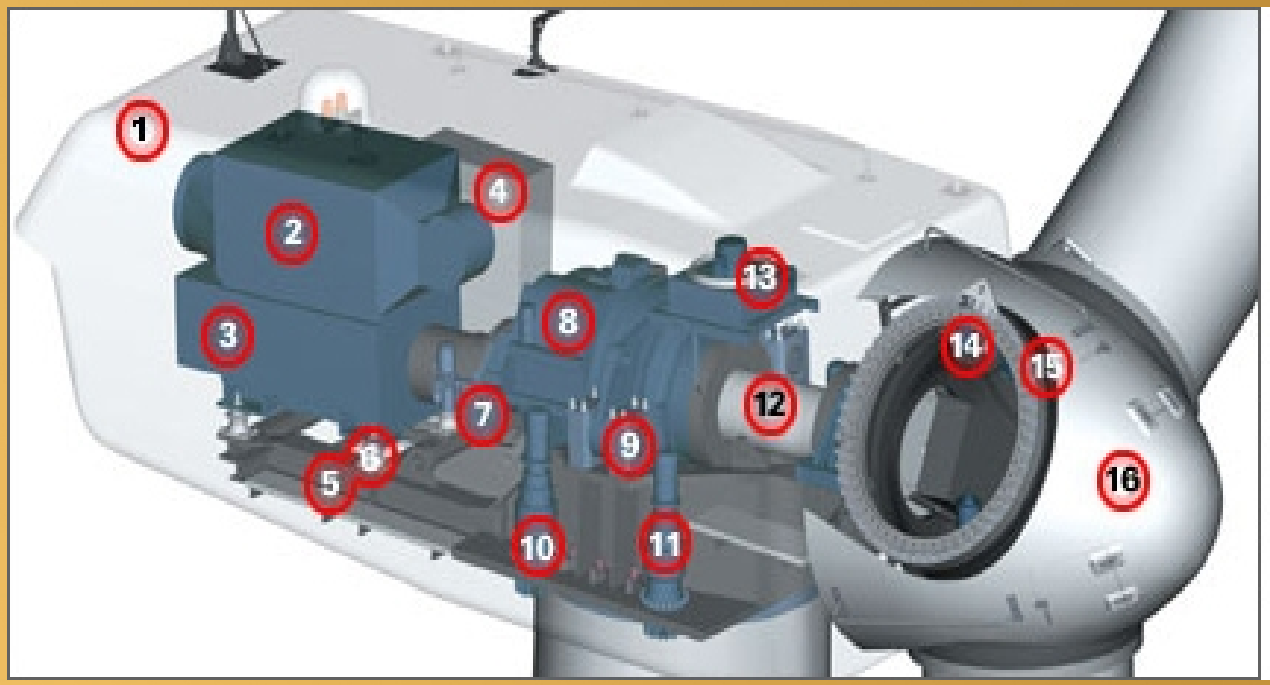
Hub height 135 m (442.8 ft)
Blade tip reaches a height of 198m (649 ft)

Hesburgh Library is approximately 168 ft. high.

This machine can generate 7.5MW of power.

GE 1.5 MW Wind Turbine
Rotor diameter 77 m
Hub height can vary 61 to 85 m depending on wind conditions at the selected site.

Major Components in The Nacelle



1. Nacelle
2. Heat Exchanger
3. Generator
4. Control Panel
5. Main Frame
6. Impact Noise Insulation
7. Hydraulic Parking Brake
8. Gearbox
9. Impact Noise Insulation
10. Yaw Drive
11. Yaw Drive
12. Rotor Shaft
13. Oil Cooler
14. Pitch Drive
15. Rotor Hub
16. Nose Cone

Advantages of HAWT

- Tall tower allows access to stronger and more uniform winds.
- The ability to pitch the rotor blades improves efficiency and control of the wind turbine.
- Most HAWT machines are self starting.

Disadvantages of HAWT

- Maintenance of the machine is much more difficult because of tower height.

The potential of Wind Power In the USA and abroad.

Wind: A Large Resource

Total wind resource in U.S. is about 3,000 Quads* or 30-times U.S. total annual energy consumption

Energy Source	Theoretical Resource*	Recoverable Resource*	Current Utilization+
Solar	46,000	>100	.06%
Wind	**3000**	**120**	**2.0%**
Biomass	--	13-26	3%
Hydro	5.8	3-4	3%

* 100 Quads equal to annual energy consumed in U.S.
+ Percent of U.S. annual energy consumption

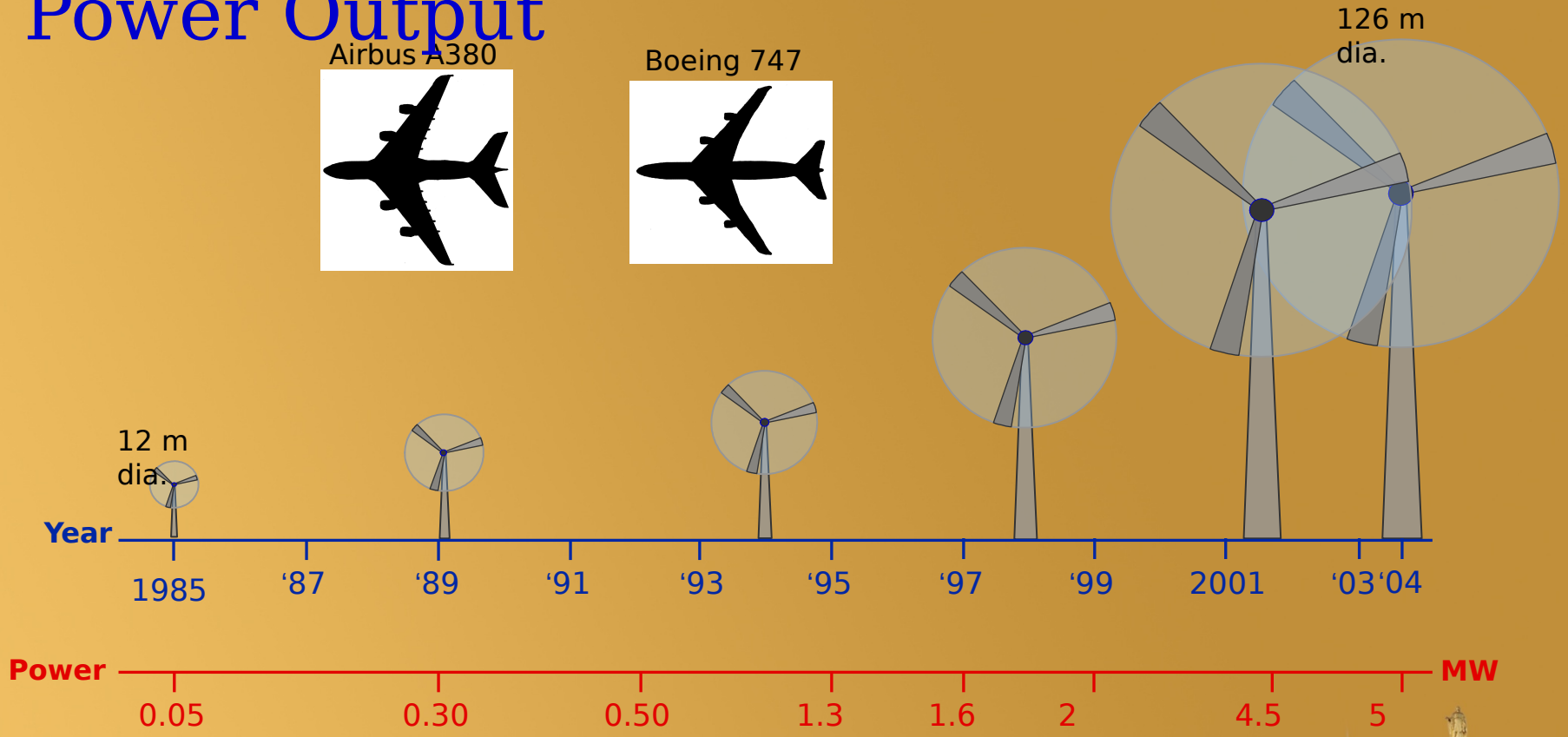
Wind Energy

- Wind Energy is a growth industry.
  - 28% average annual growth rate during the past ten years
  - Spain, Germany and Denmark are close to meeting their goal of generating 30% of their electric power need from wind energy
- Wind Energy in the United States.
  - In 2009, the U.S. wind industry represented approximately 35% of new capacity
  - Recently, reached the largest wind capacity in the world
  - But only accounts for ~2.0% of annual electric usage

DOE Proposal: 20% by 2030

- To produce 20% of US electrical production with wind by 2030
- Would displace 50% of electric utility natural gas consumption and 18% of coal consumption
- Provide an annual reduction of 825 million metric tons of CO_2 emission
- Provide an annual savings of 4 trillion gallons of water

Growth In Wind Turbine Size and Power Output



Challenges facing the wind power industry.

Challenges Facing the Wind Power Industry

- Lower operational cost by minimizing down time due to component failure.
  - Need to lower the cost of wind generated electric power.
  - Need to optimize power in start-up region.
  - Improve performance in wind farms.
- Need to decrease acquisition cost.
  - Lower unsteady blade loading so that lighter blades can be used. Blade weight drives the cost of a wind turbine.

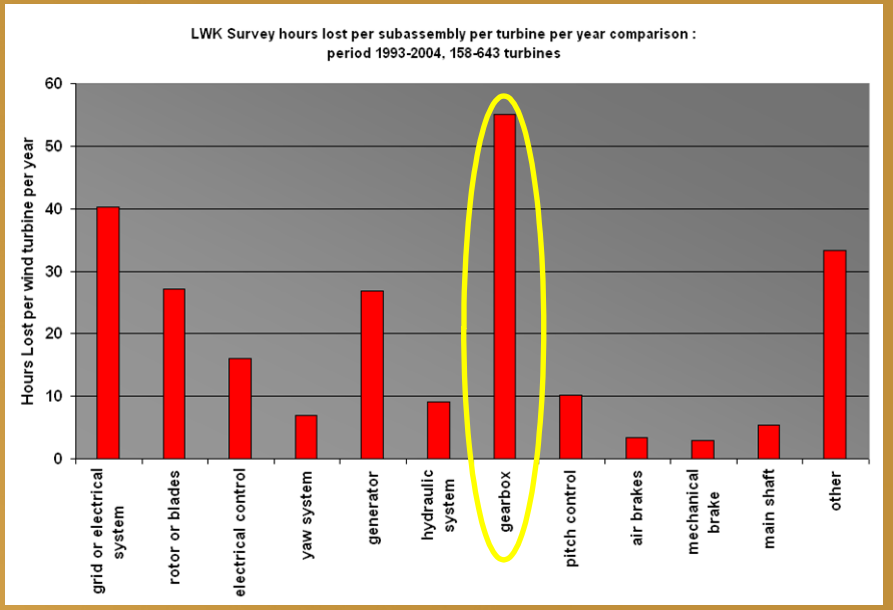
Wind Industry Challenges

Energy Output: Revenue

- Low capacity factors: ~35%
- Systems not optimized for more probable low wind speeds (~70% of operation)
- Constricted capital markets require higher returns than feasible in lower-class wind locations with current technology.
- Pitch and yaw systems have slower response times than wind speed and direction changes.

A need to address **ALL** of these challenges.

System Failures: Cost



A need to reduce the weight of and aerodynamic loading on rotors.

Can Be Addressed with Active On-rotor Flow Control